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SAFETY TESTING OF LITHIUM (SULFUR DIOXIDE) BATTERY FOR EXPENDABLE, MOBILE, ASW, TRAINING TARGET (EMATT)

BY E. R. PEED, M. B. KEPNER, J. A. BARNES, AND F. C. DEBOLD

RESEARCH AND TECHNOLOGY DEPARTMENT

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The Naval Surface Warfare Center, White Oak, was requested to perform a safety evaluation of EMATT (Expendable, Mobile, ASW, Training Target) battery system. The EMATT unit contains fifteen lithium sulfur dioxide (Li/SO_2) size "DD" cells which provide required power to operate the vehicle. The testing was conducted under the guidelines of NAVSEA NOTICE 9310. This report describes the methods and the results obtained from the safety testing. The test results indicate that the power source meets the safety requirements provided by NAVSEA NOTICE 9310.

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FOREWORD

The Naval Surface Warfare Center, White Oak, was requested to perform a safety evaluation of EMATT (Expendable, Mobile, ASW Training Target) battery system. The EMATT unit contains fifteen lithium sulfur dioxide (Li/SO_2) size "DD" cells which provide the required power to operate the vehicle. The testing was conducted under the guidelines of NAVSEA Notice 9310. The report describes the methods and the results obtained from the safety testing. The test results indicate that the power source meets the safety requirements provided by NAVSEA Notice 9310. This work was sponsored by Naval Sea Systems Command, SEA 63T22 (T. B. Atkins).

Approved by:

Carl E. Mueller

CARL E. MUELLER, Head
Materials Division

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CHAPTER 1

INTRODUCTION

The U.S. Navy has developed the Expendable, Mobile, Anti-Submarine Warfare (ASW) Training Target, EMATT (Figure 1-1). The EMATT unit is an air or surface launched vehicle which performs maneuvers in the ocean and emits a magnetic or acoustic signature that is monitored by airborne and surface ships for training purposes. The duration of operation of the vehicle is approximately three hours.

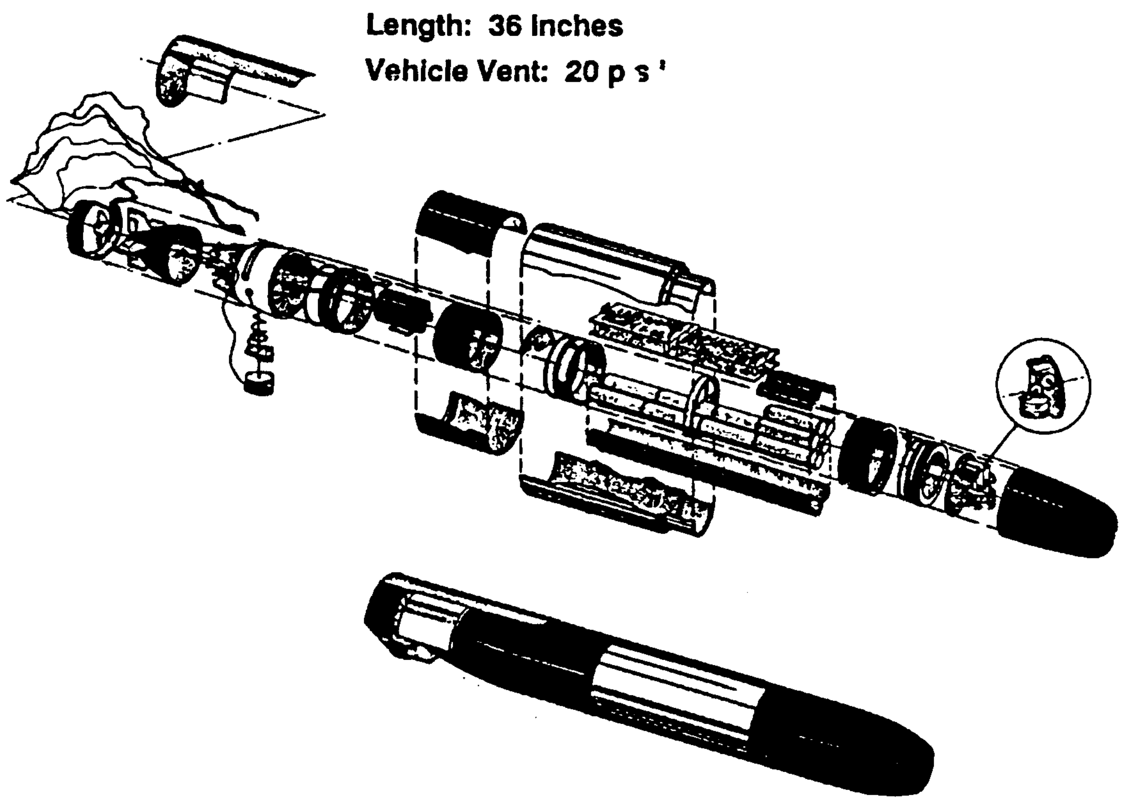

FIGURE 1 1. EXPENDABLE, MOBILE, ASW TRAINING TARGET (EMATT)

The EMATT unit was first designed to use a lithium/sulfuryl chloride (Li/SO_2Cl_2) "DD" size, 15-cell battery pack. This battery was replaced because of performance related failures after the batteries had undergone high, low, and ambient temperature storage tests. The battery exhibited substantial voltage delay and capacity loss of approximately 32 percent after one month of storage and 64 percent after two months of storage.[1] The present battery pack contains 15 "DD" size lithium/sulfur dioxide (Li/SO_2) cells. This work was sponsored by Naval Sea Systems Command, SEA 63T22 (T.B. Atkins).

CHAPTER 2

POWER SOURCE DESCRIPTION

CELL DESCRIPTION

The EMATT battery contains cells manufactured by Power Conversion, Inc. (PCI). The cells have the following characteristics:

- Chemistry: Li/SO_2
- Size: "DD"
- Weight: 155g
- Construction: spirally wound; stainless steel can
- Open Circuit Voltage: 3.0
- Nominal Operating Voltage: 2.6
- Fuse: 15 amp pico fuse in positive lead
- Polarity: pin positive, can negative
- Vent: two slit vents on negative end of can

The cell fuse is contained in potting above the header (Figures 2-1 and 2-2). Each cell contains two vents on the bottom of the cell can (Figures 2-1 and A-3 of the appendix). The slit vents are approximately one eighth of an inch in length.

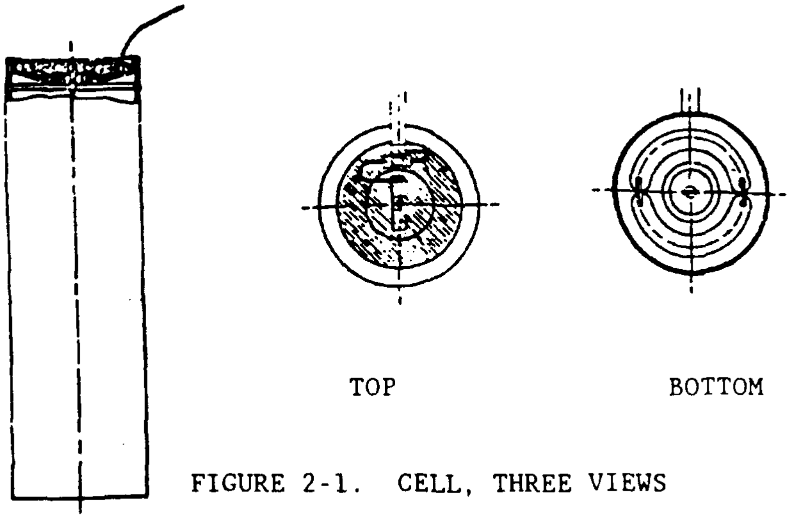

FIGURE 2-1. CELL, THREE VIEWS

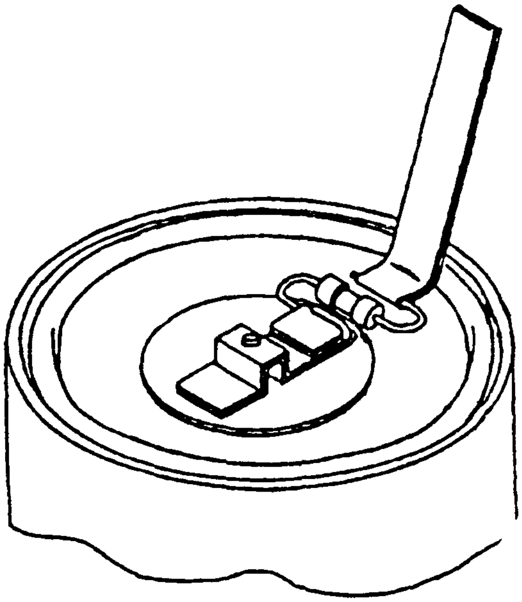

FIGURE 2-2. CELL 15 AMP PICO FUSE

BATTERY PACK DESCRIPTION

The EMATT battery pack contains 15 of the cells described above. The battery has the following characteristics:

- 15 "DD" Li/SO_2 cells in series
- Weight: 2.83 kg
- 75±2°C thermal fuse, Microdevices 9178 (or equivalent)[2]
- 8 amp electrical fuse, Tracor Inc. No. 315-008 (or equivalent)[2]

The cell configuration (Figure 2-3) consists of three sticks (cells arranged end to end) of four cells each and three sticks of one cell each. Each stick is placed in an aluminum cylinder that contains a slit the length of the cylinder. The sticks are coated with thermal grease prior to insertion into the cylinders to facilitate heat transfer (Figure A-1).[2] Spacers are inserted between cells in the four-cell sticks to allow for proper vent operation. The aluminum cylinders, containing the four-cell sticks, are glued together to form the battery pack. The thermal and electrical fuses are connected in series in the negative lead of the battery and secured to the aluminum cylinder between two of the four-cell sticks at approximately half the length of the battery. The cell numbers as shown in the figures do not coincide with the order in which the cells are connected in series. The end view of the battery pack provides a detailed view of the intercell connections (welded nickel tabbing) (Figure 2-4).

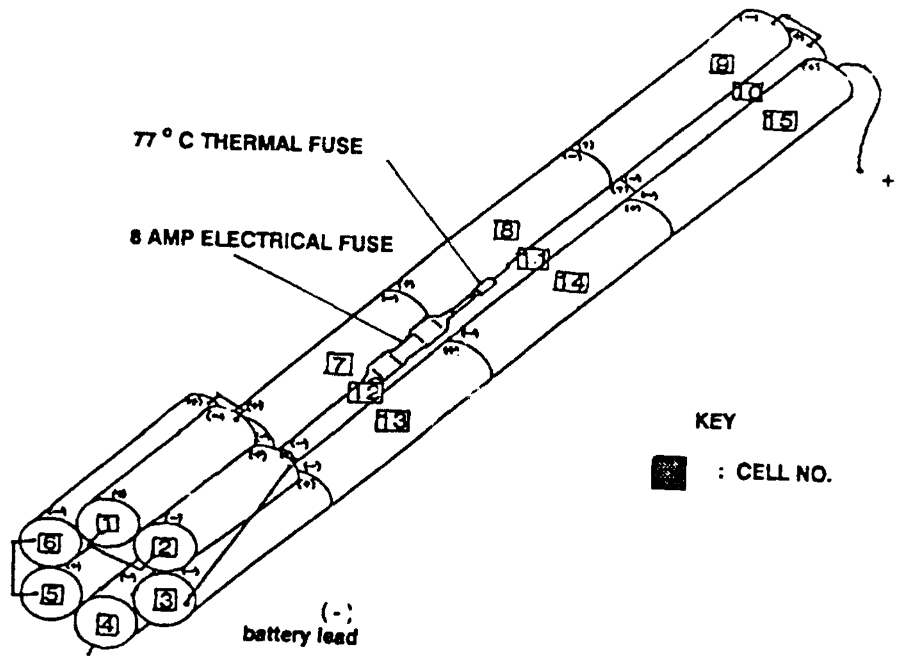

FIGURE 2-3. BATTERY PACK CONFIGURATION, FUSE PLACEMENT

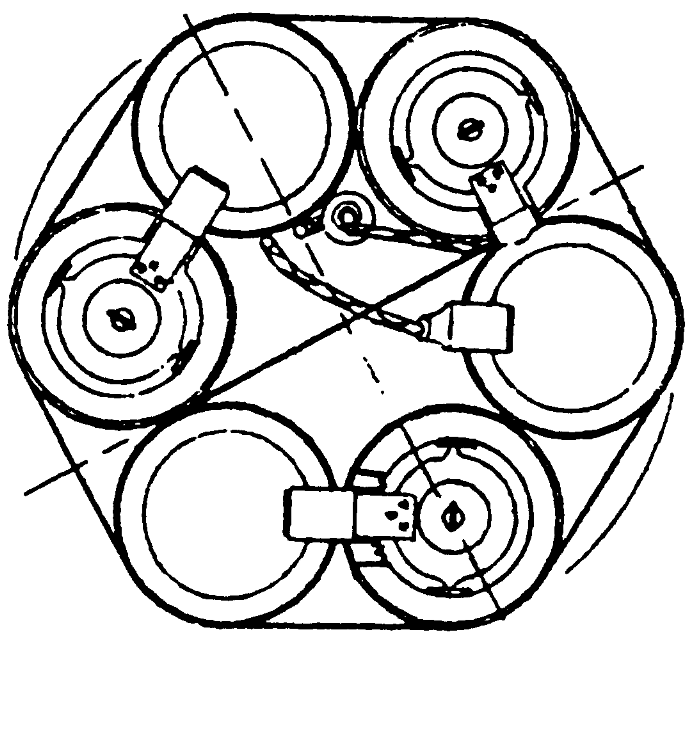

FIGURE 2-4. BATTERY PACK END VIEW

CHAPTER 3

SAFETY TESTING OF Li/SO_2 BATTERY

DESCRIPTION OF TESTS

Testing of the EMATT battery was conducted at the Naval Surface Warfare Center (NAVSWC), White Oak, during April and May of 1988. The battery packs tested were installed in the EMATT vehicle. The vehicles did not contain any electronics or filler material. The housing, including all seals and joints, was representative of production units. The tests conducted (as required by NAVSEA Notice 9310)[3] are described in Table 3-1.

Short Circuit Test

The battery was shorted by the use of a remotely controlled relay. The relay, rated at 100 amp 250V, was employed for short circuit testing to eliminate the resistance of the leads between the control room and the test site. The resistance was minimized by placing the relay in the test chamber next to the battery. The resistance of the circuit through the relay was approximately 100 milliohms. The short circuit test was terminated after one or several of the individual cell pico fuses opened.

High Temperature Test

Two independently controlled heating tapes were used (Figure 3-1). The tapes were Thermolyne Brisk Heat flexible electric heating tapes, 120V, 416 watts, $\frac{1}{2}$ inch wide and eight feet in length. The heating tape covering the six-cell end (the nose end), of the battery pack was eight feet in length and designated as heat tape 1. The heating tape covering the aft end of the battery was five and one half feet in length and designated as heat tape 2. The middle of the battery was not covered with heating tape because of the space constraints dictated by the vehicle. Each heating tape was controlled with a variable autotransformer (Variac). The Variacs were adjusted to provide a temperature increase of approximately 10°C per minute. A faster heating rate was not possible because of limitations of the heating tape.

Forced Discharge at a Constant Current of 6 Amps 150 Percent into Voltage Reversal

A power supply was set at a constant current of six amps, 75 percent of the pack fuse, for each test. The power supply (Sorensen 200V, 15 amp) voltage was initially set at 45V for the first test and 5V for the second test. This change to a lower initial voltage was made to decrease the probability of sending a power surge through the system. The power supply voltage was increased as the battery entered voltage reversal to maintain a constant current of 6 amps. A seven ohm, 250 watt ballast resistor network (three two ohm and one one ohm 250 watt resistors in series) was used in the circuit.

TABLE 3-1. BATTERY PACK SAFETY TESTS

No. of Batteries Tested	Test	Test Description
3- Pack fuses removed	Short Circuit followed by High Temperature Test	Short activated by 100 amp 250 V relay. Two independent heating tapes used for each pack.
2- Pack fuses removed	Forced Discharge at a Constant Current of 6 Amps 150% into Voltage Reversal	Power supply set at 6 amps (current limiting). Power supply set initially at 45 V for first test and 5 V for second test. Ballast resistor of 7 ohms.
3- Pack fuses included	Safety Device Test	Power supply set at 6 amps (current limiting). Power supply set initially at 45 V for first test and 5 V for second and third tests. Power supply voltage was increased as the battery entered reversal. Ballast resistor, 10 ohms for first test, 7 ohms for second and third tests.

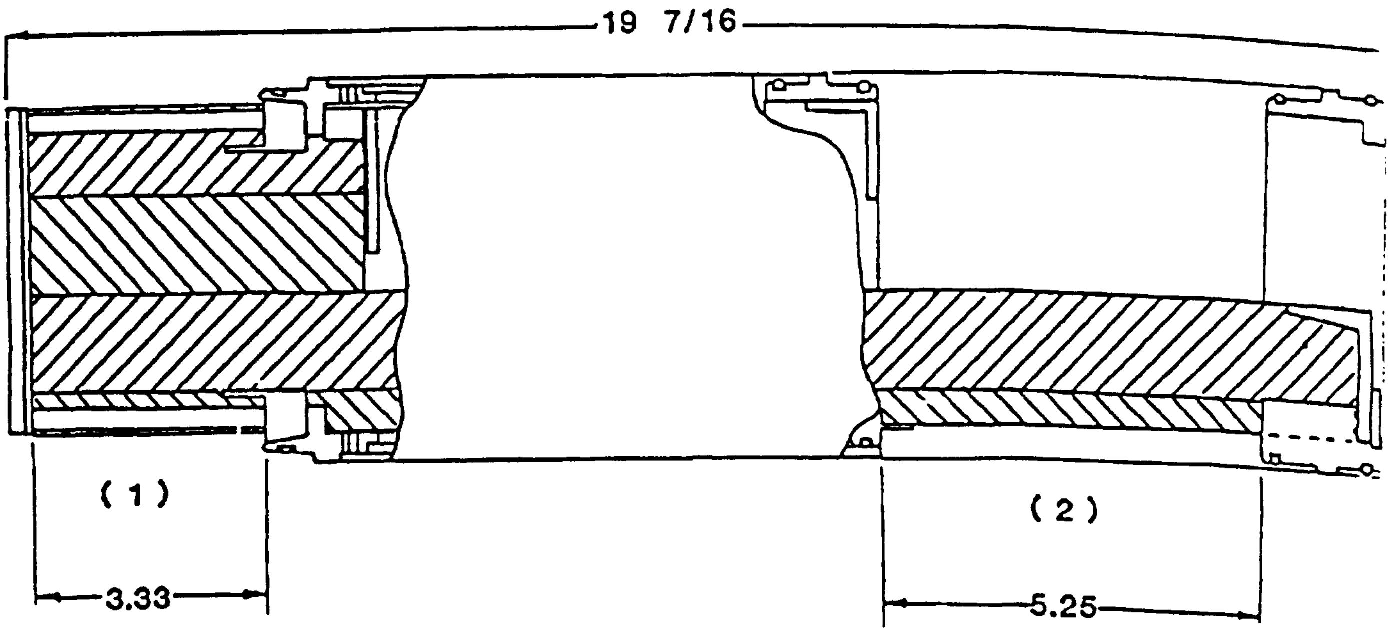

FIGURE 3-1. HEAT TAPE PLACEMENT ON BATTERY PACK (LENGTH IN INCHES)

Safety Device Test

The safety device test was identical to the forced discharge into reversal test except that both of the battery fuses were included in the safety device test. The ballast resistor value was changed in the safety device test from 10 ohms, 250 watts, to a 7 ohm network (identical to the seven ohm resistor described for the forced discharge into reversal test) because the 10 ohm resistor did not have a high enough power rating. The initial power supply voltage was adjusted as described for the second forced discharge into reversal test.

Data Acquisition

A Fluke datalogger (model 2240C) interfaced with an IBM PC using Lotus Measure was employed to collect data. Five thermocouples were placed on the battery (Figure 3-2). The following data were acquired for each test:

- Temperature of battery pack: Thermocouples 1 through 5
- Ambient temperature: Thermocouple 6
- Battery Voltage
- Pressure: Pressure Transducer Attached to Vehicle
- Current

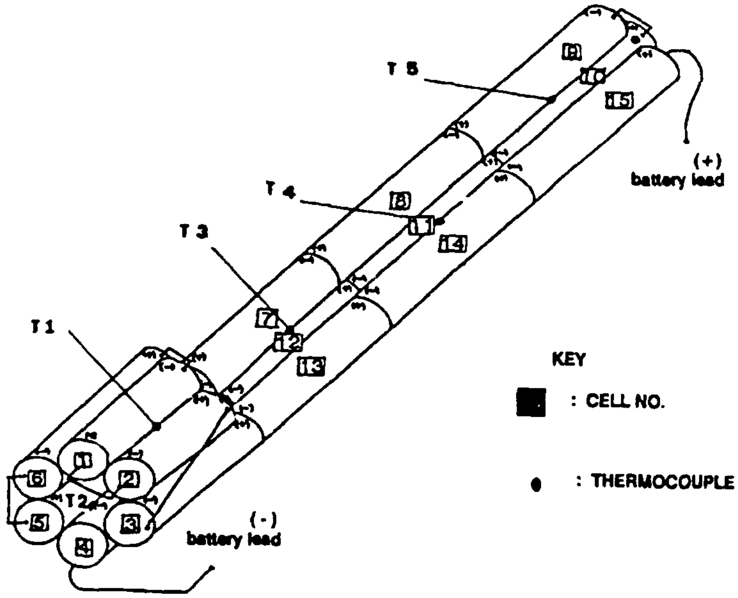

FIGURE 3-2. THERMOCOUPLE PLACEMENT ON BATTERY PACK

RESULTS

Short Circuit and High Temperature Tests

Data from the short circuit and high temperature tests are given (Table 3-2). When the short circuit was activated, one of the cell 15 amp pico fuses opened in each battery in less than five seconds. During three high temperature tests, the plastic sections of the vehicle began to melt and expand after 10-14 minutes of heating. Each unit vented gases; lithium fires occured. Unit three vented and the plastic midsection burned mildly. "Unit venting" refers to the release of gases from the vehicle through weak spots in the hot plastic hull. Units one, two, and three opened after 29, 31, and 14 minutes at approximate temperatures of 150°C, 112°C, and 91°C, respectively. As the cells vented, temperatures above 700°C were measured. The number of vented cells was determined by a post mortem conducted on each battery. Temperature versus time and pressure versus time plots are given (Figures 3-3 through 3-9) for each test.

TABLE 3-2. RESULTS: SHORT CIRCUIT AND HIGH TEMPATURE TESTS

	SHORT CIRCUIT	HEAT TAPE				
UNIT	TIME TO CIRCUIT OPENING	TIME TO UNIT VENTING MIN	LOCATION OF OPENING	MAXIMUM TEMPERATURE AT OPENING (°C)	MAX. PRESSURE (P.S.I.)	VENTINGS
1	ALL UNITS: A 15 AMPERE PICO FUSE OPENED IMMEDIATELY, LESS THAN 5 SECONDS	29	NOSE	THERMOCOUPLE 4: 146 THERMOCOUPLE 5: 157	4.5	ALL 15 CELLS
2		31	NOSE	THERMOCOUPLE 4: 108 THERMOCOUPLE 5: 114	2.6	ALL CELLS EXCEPT 3&8
3		14	MIDSECTION	THERMOCOUPLE 1: 91	7.7	ALL CELLS EXCEPT 8

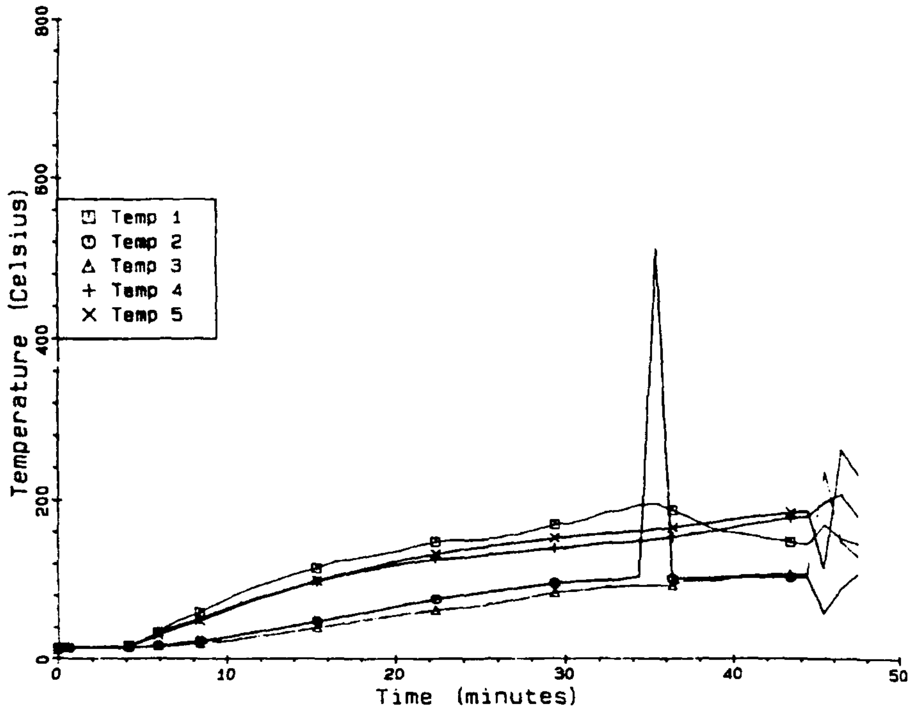

FIGURE 3-4. SHORT CIRCUIT/ HIGH TEMPERATURE, PACK 1, TEMPERATURE VERSUS TIME

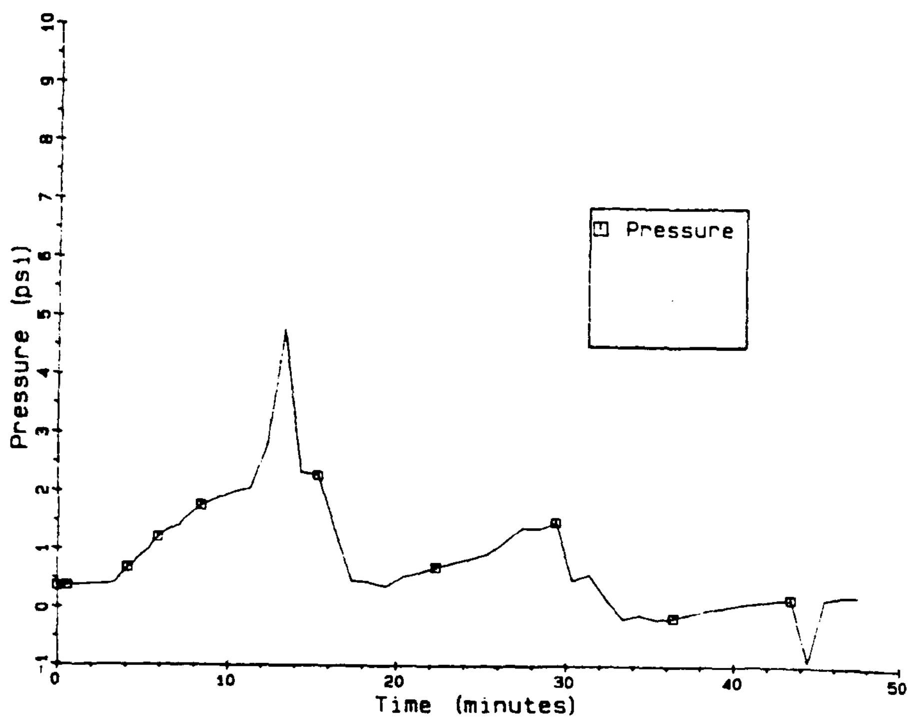

FIGURE 3-5. SHORT CIRCUIT/ HIGH TEMPERATURE, PACK 1, PRESSURE VERSUS TIME

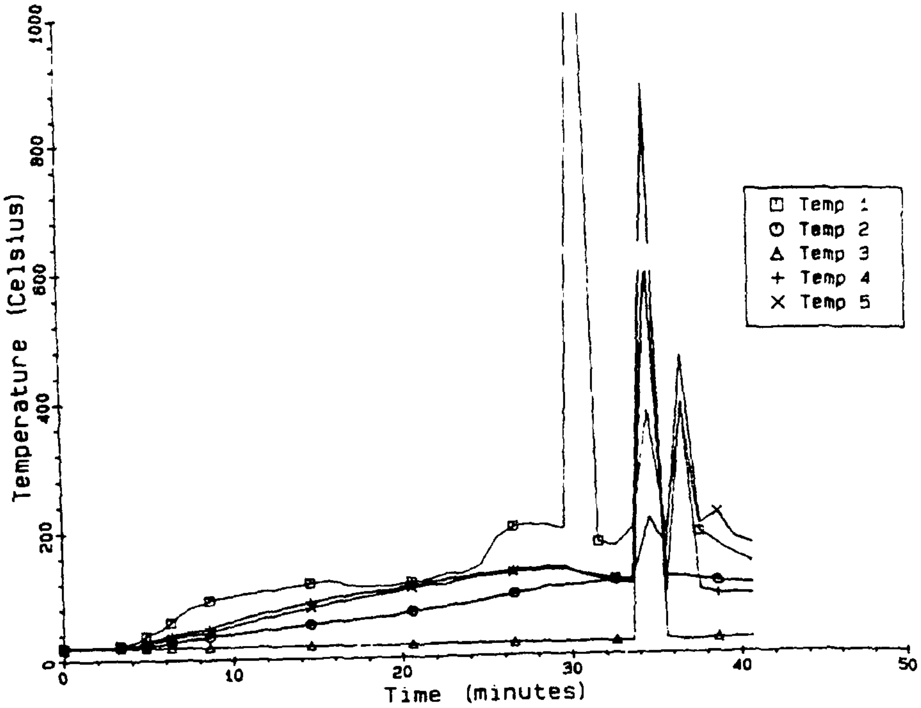

FIGURE 3-6. SHORT CIRCUIT/ HIGH TEMPERATURE, PACK 2, TEMPERATURE VERSUS TIME

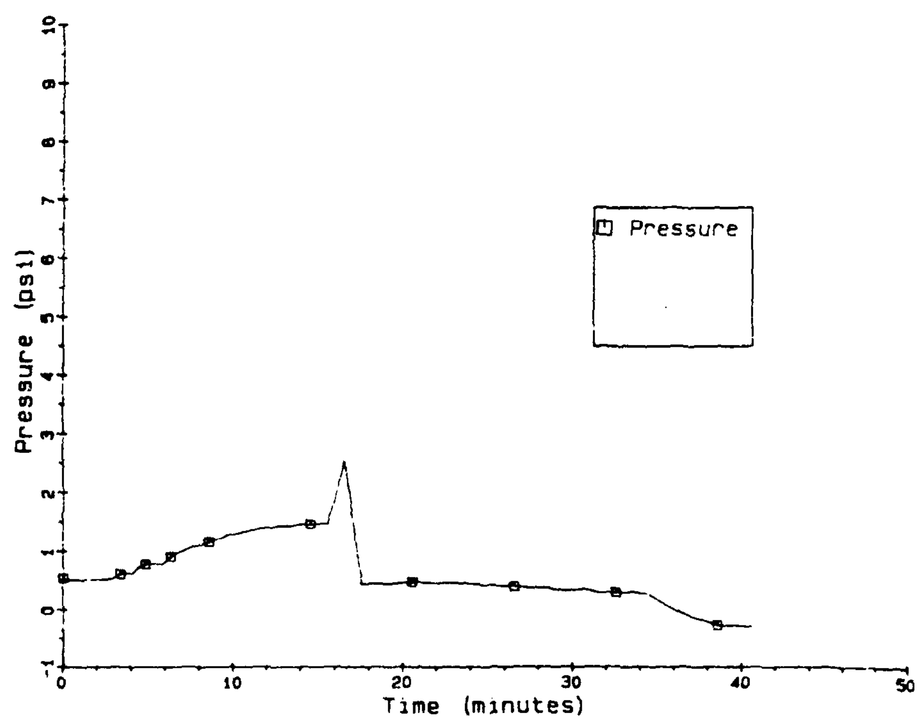

FIGURE 3-7. SHORT CIRCUIT/ HIGH TEMPERATURE, PACK 2, PRESSURE VERSUS TIME

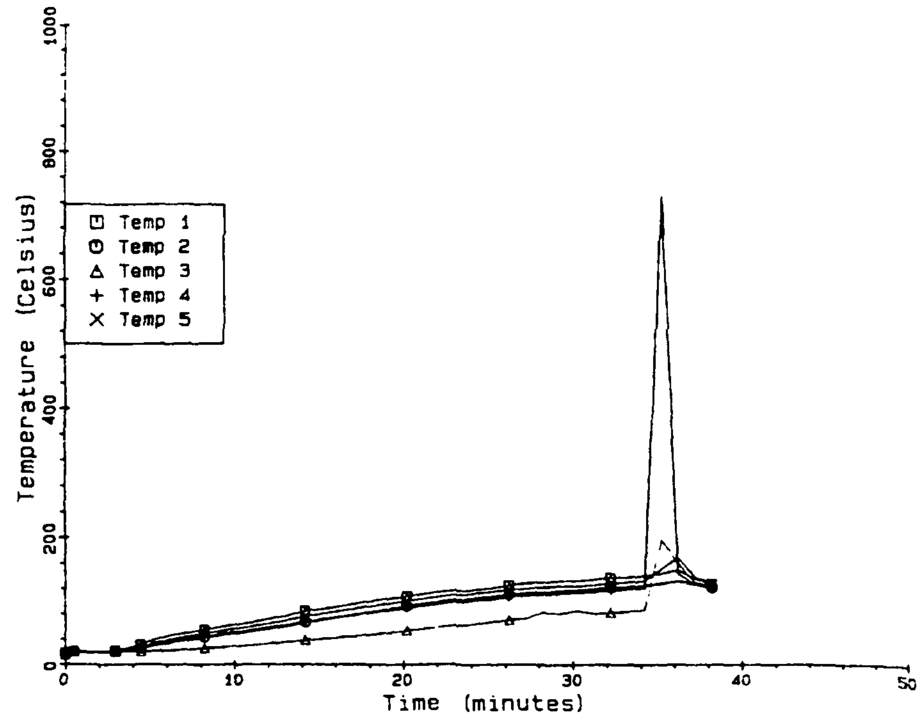

FIGURE 3-8. SHORT CIRCUIT/ HIGH TEMPERATURE, PACK 3, TEMPERATURE VERSUS TIME

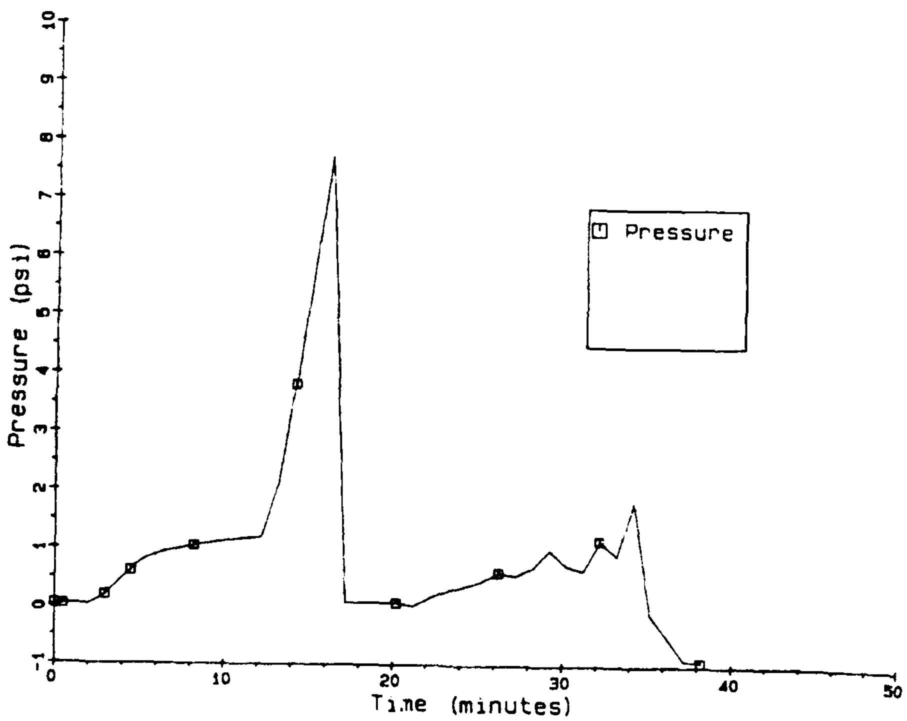

FIGURE 3-9. SHORT CIRCUIT/ HIGH TEMPERATURE, PACK 3, PRESSURE VERSUS TIME

Forced Discharge at 6 amps 150 Percent into Voltage Reversal

Data for each forced discharge into voltage reversal test are summarized in Table 3-3. The approximate maximum temperatures reached for units four and five were 152^{0}C (thermocouple 4) and 150^{0}C (thermocouple 5), respectively. The maximum temperatures occurred approximately $2\frac{1}{2}$ minutes prior to the battery going into voltage reversal. Each battery delivered approximately 15 A-hrs of capacity prior to voltage reversal. The vehicles were not deformed or melted as a result of the cell ventings. The battery voltage versus time and temperature versus time plots are given for each test (Figures 3-10 through 3-13).

TABLE 3-3. RESULTS: FORCED DISCHARGE AT CONSTANT CURRENT OF 6 AMPS 150 Percent INTO VOLTAGE REVERSAL

UNIT	ELAPSED TIME TO FIRST VENTING	APPROX. TEMPERATURE AT VENTING (°C)	ELAPSED TIME INTO REVERSAL	VENTINGS (CELL#)
4	2 HRS 46 MIN	125	2 HRS 50 MIN	3, 5, 7, 8, 9, 11, AND 14
5	2 HRS 47 MIN	121	2 HRS 52 MIN	1, 2, 3, 5, 10, 11, 12, AND 13

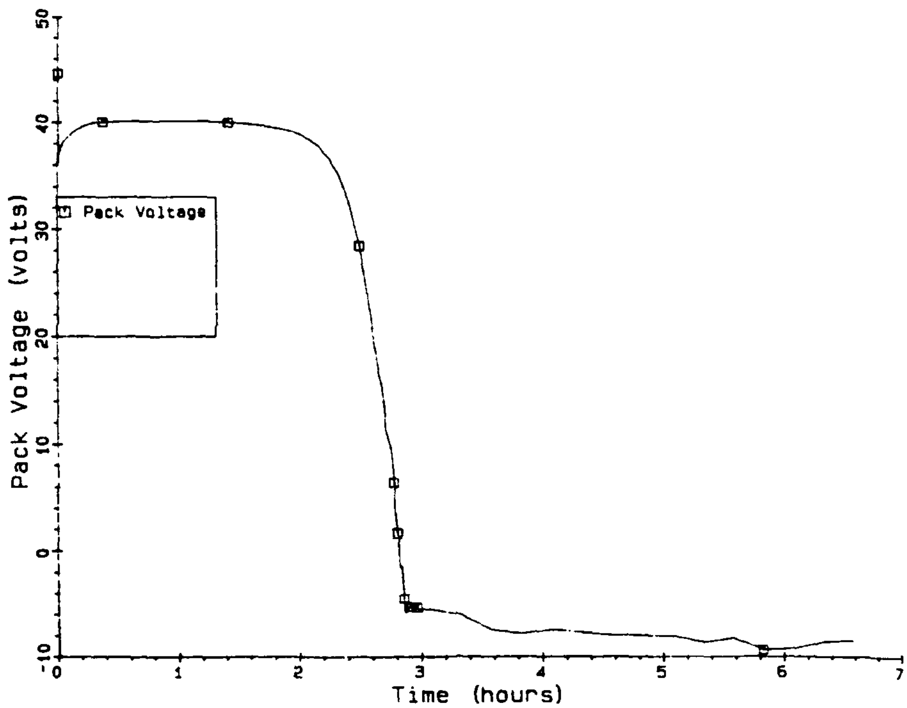

FIGURE 3-10. FORCED DISCHARGE INTO REVERSAL, PACK 4, VOLTAGE VERSUS TIME

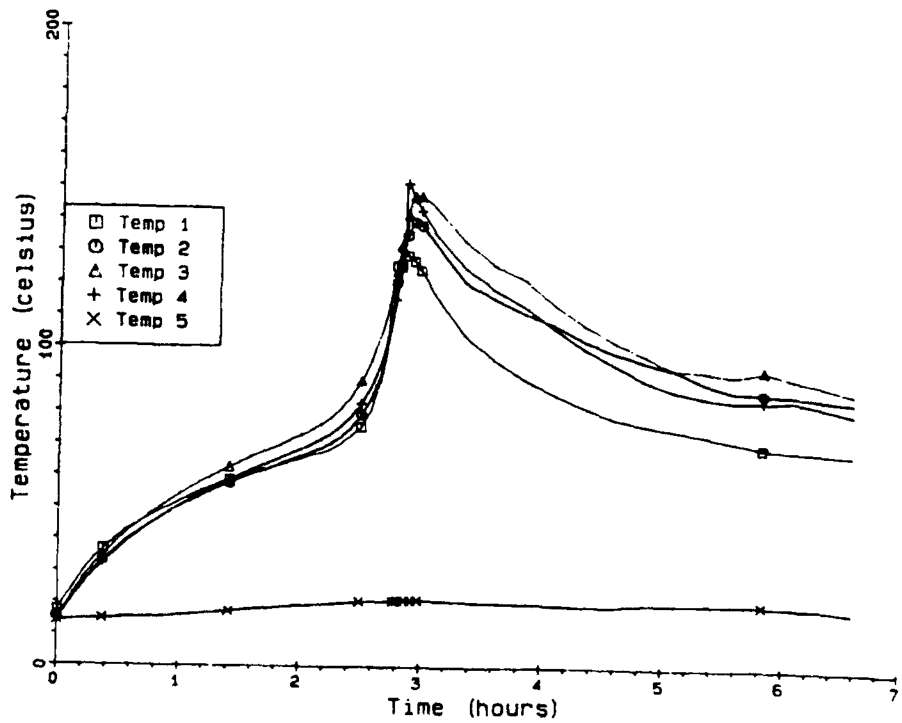

FIGURE 3-11. FORCED DISCHARGE INTO REVERSAL, PACK 4, TEMPERATURE VERSUS TIME

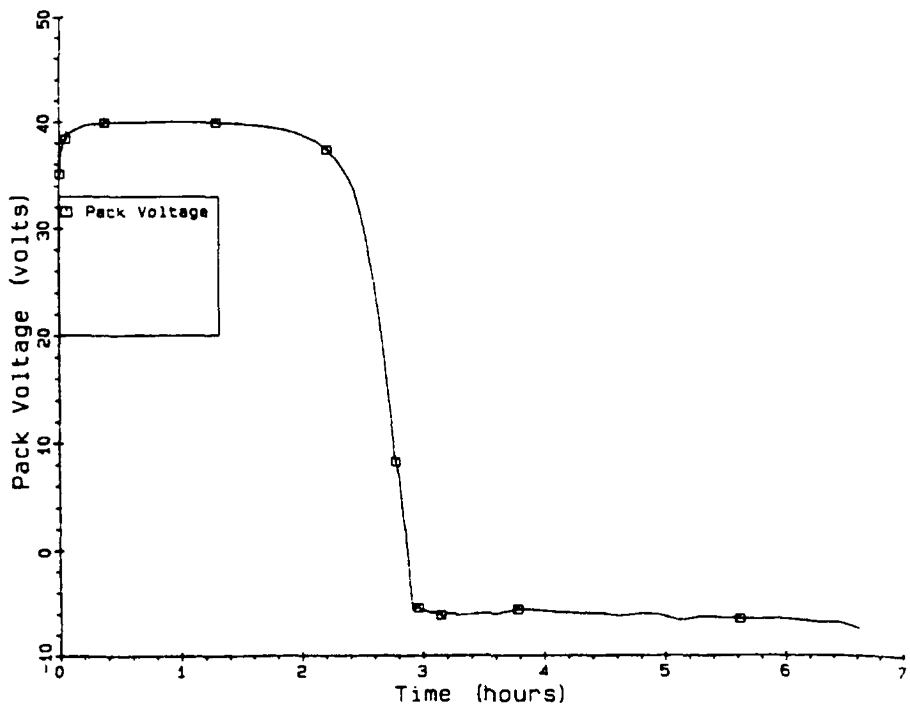

FIGURE 3-12. FORCED DISCHARGE INTO REVERSAL, PACK 5, VOLTAGE VERSUS TIME

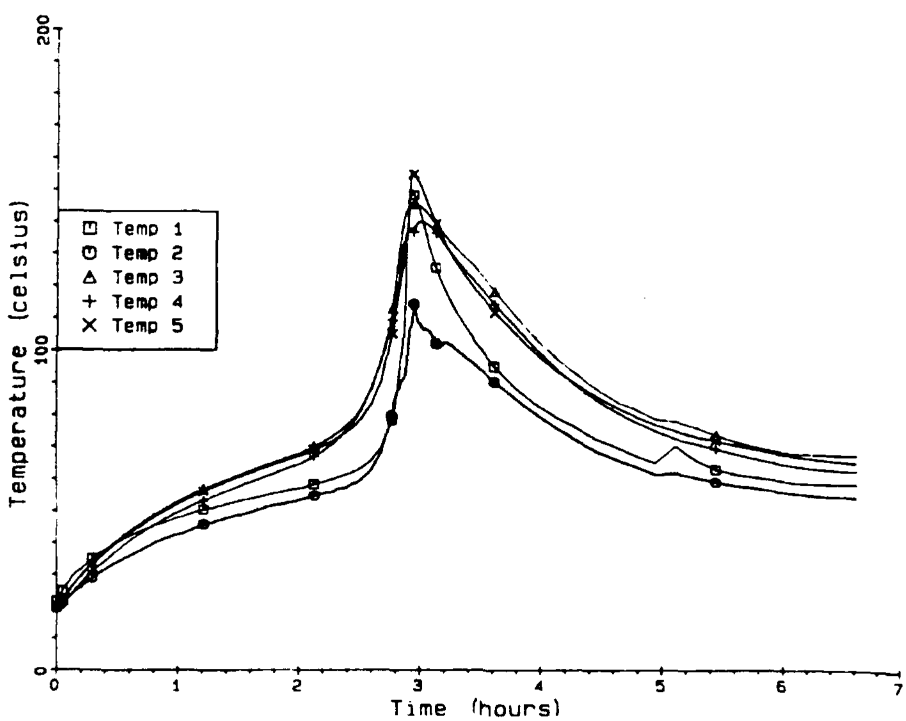

FIGURE 3-13. FORCED DISCHARGE INTO REVERSAL, PACK 5, TEMPERATURE VERSUS TIME

Safety Device Test

Units six and nine reached a maximum temperature of approximately 73°C at which time the thermal fuses opened. The temperature of unit eight approached the thermal fuse rating, 75±2°C, but the thermal fuse did not open and the battery went into voltage reversal with associated cell ventings. The cause of the thermal fuse failure in unit eight could not be unequivocably established, but an analysis of the data in conjunction with a post-test examination of the fuse allowed a hypothesis to be produced. As the fuse approached its temperature limit of 73°C, it began to open. By design, for a fuse to open a contact must move inside the fuse. As the contacts began to open, the power supply responded to the increased resistance of the circuit by increasing its output voltage to its preset limit of 45 volts. This voltage spike may have been sufficient to strike an arc between the opening contacts which welded them closed. In interpreting this hypothetical behavior, one must recognize that the maximum current and voltage values were within the specification limits of the fuse, but that the fuse was designed and rated for use in an AC circuit. The characterisitics of the fuse in a DC circuit have not been tested. On the basis of this hypothesis, the power supply's voltage limit was set as low as possible in tests 6 and 9. The fuses in these systems behaved as expected. Because the fuse failure in test 8 may have represented an experimental artifact, this fact did not result in a negative evaluation of the system proposed for fleet use. The battery voltage versus time and temperature versus time plots are shown for each test (Figures 3-14 through 3-19). The results of the tests are also summarized below (Table 3-4).

TABLE 3-4. RESULTS: SAFETY DEVICE TEST

UNIT	MAXIMUM TEMPERATURE (°C)	BALLAST RESISTOR (OHMS)	8 AMP ELECTRICAL FUSE	77°C THERMAL FUSE	VENTINGS (CELL #)
6	74	7	CLOSED	OPEN	NONE
8	143	10	OPEN	CLOSED	2, 8, 9, 11, AND 15
9	72	7	CLOSED	OPEN	NONE

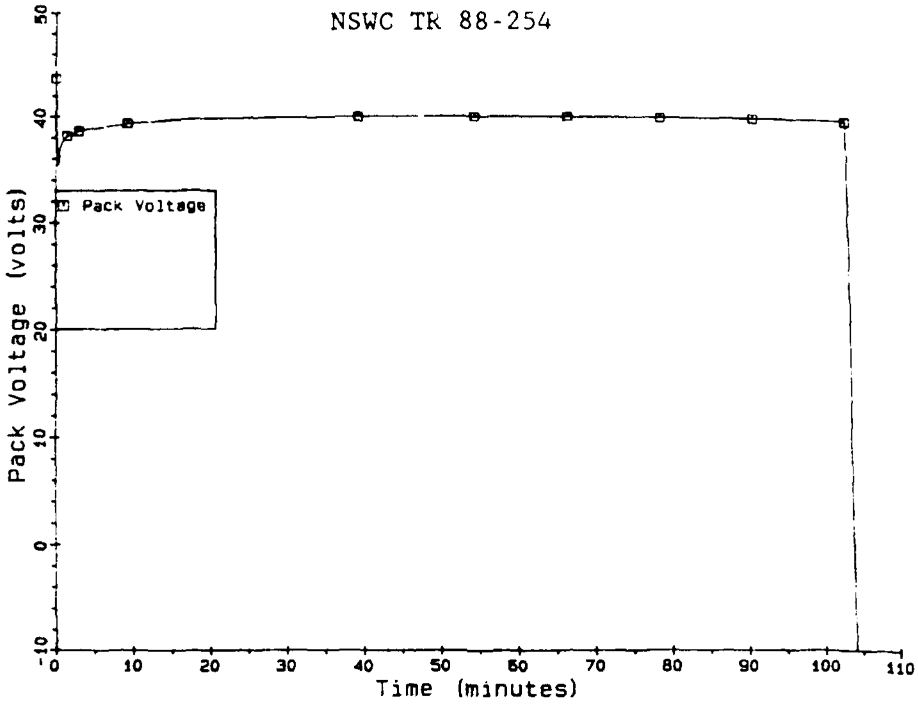

FIGURE 3-14. SAFETY DEVICE TEST, PACK 6, PACK VOLTAGE VERSUS TIME

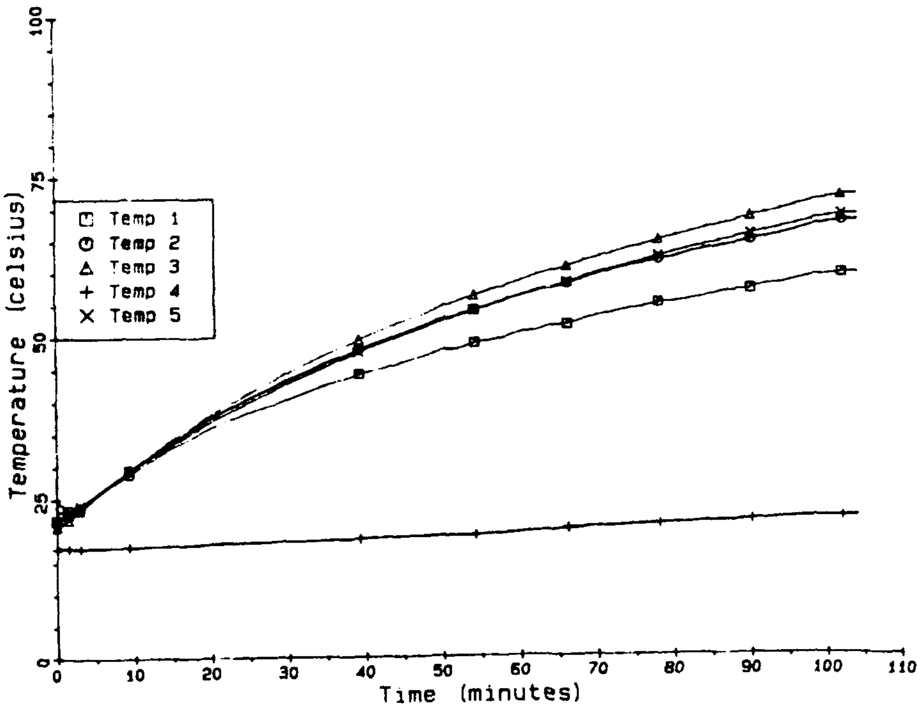

FIGURE 3-15. SAFETY DEVICE TEST, PACK 6, TEMPERATURE VERSUS TIME

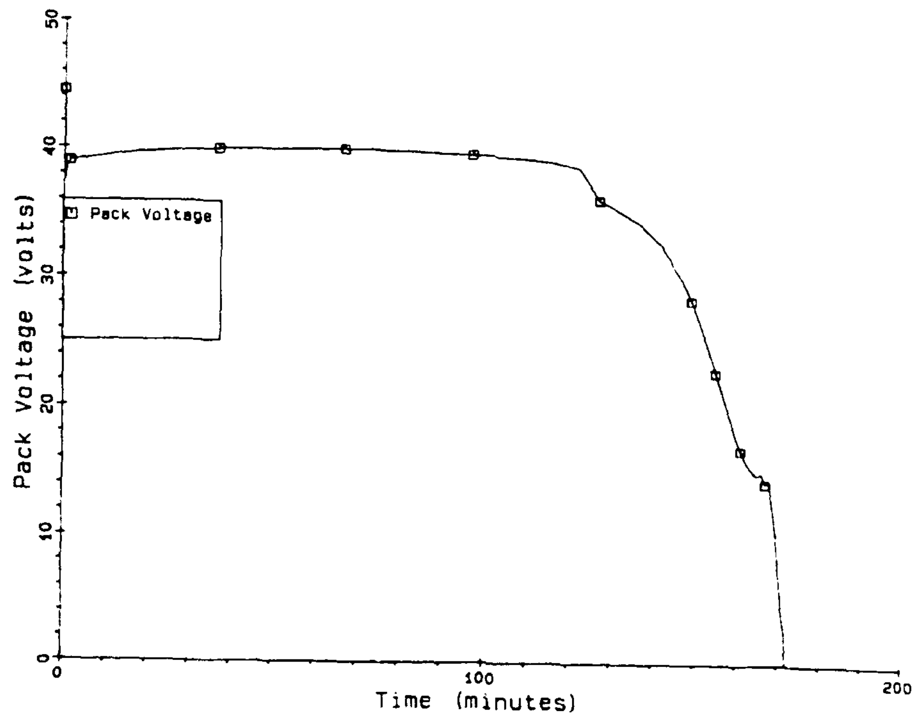

FIGURE 3-16. SAFETY DEVICE TEST, PACK 8, PACK VOLTAGE VERSUS TIME

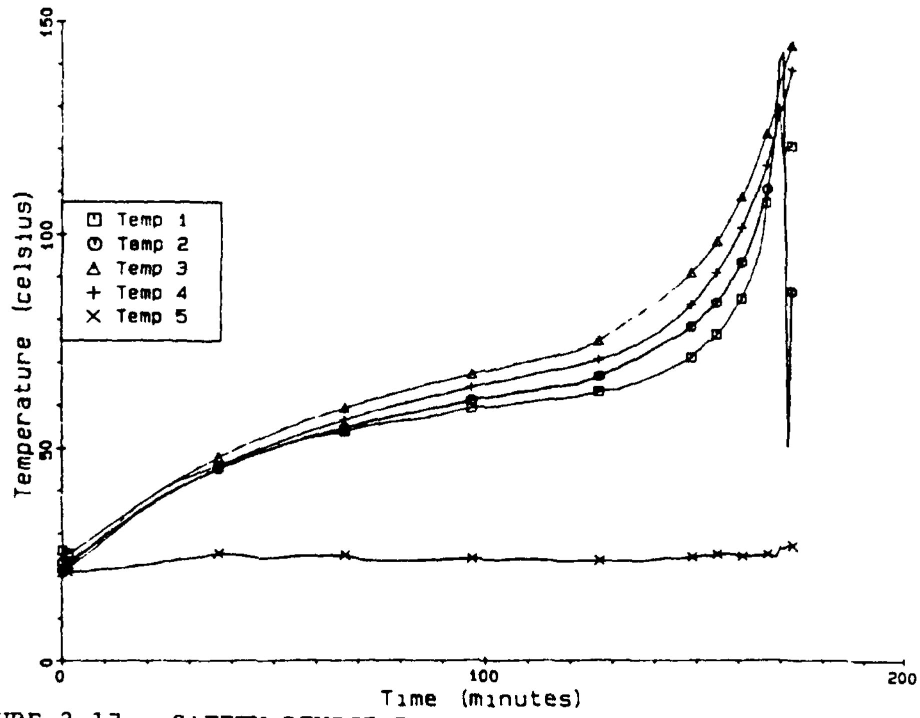

FIGURE 3-17. SAFETY DEVICE TEST, PACK 8, TEMPERATURE VERSUS TIME

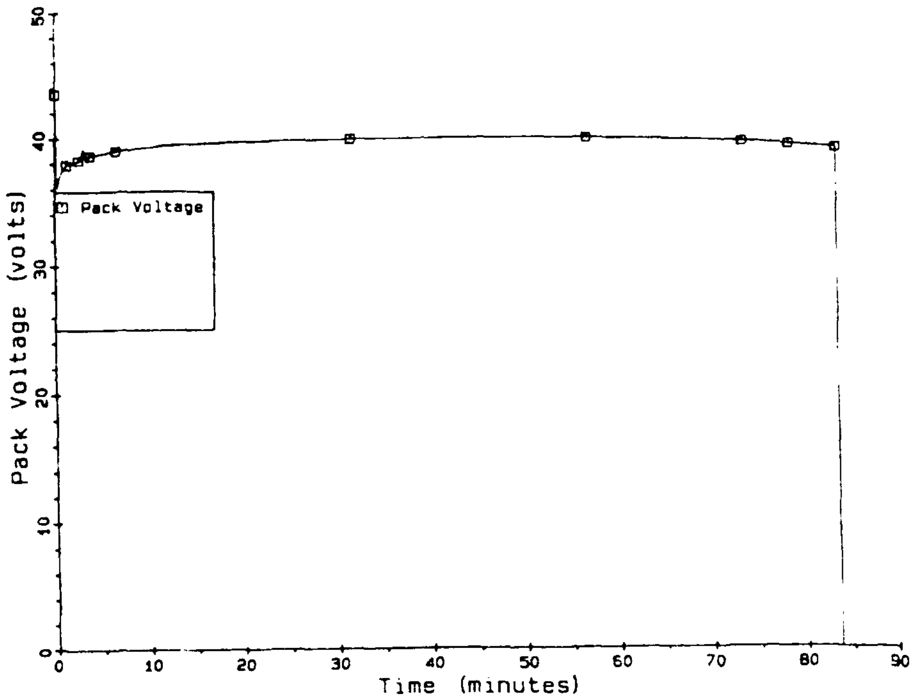

FIGURE 3-18. SAFETY DEVICE TEST, PACK 9, PACK VOLTAGE VERSUS TIME

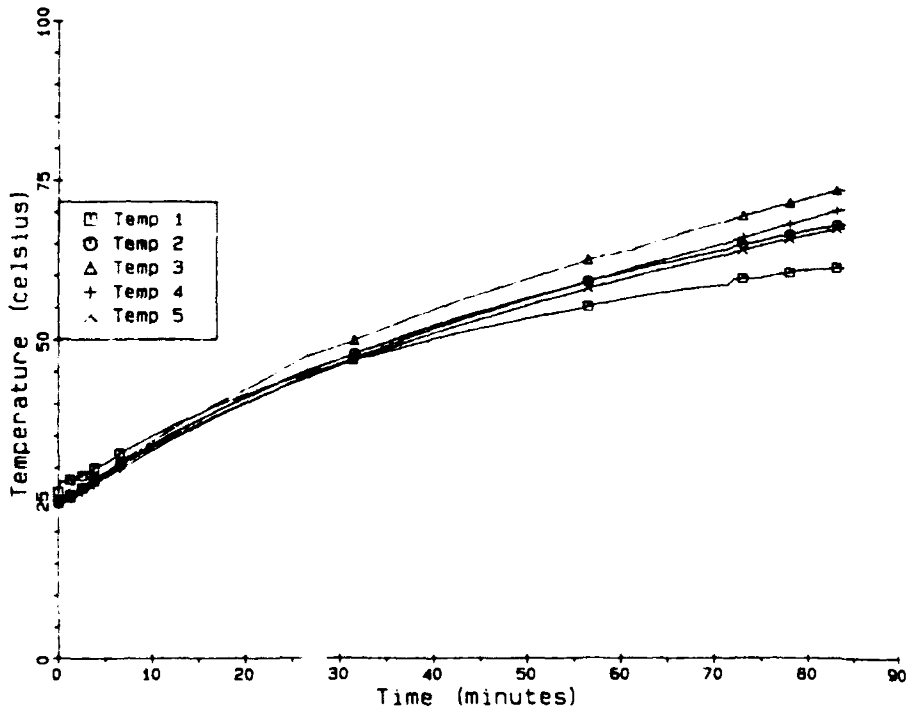

FIGURE 3-19. SAFETY DEVICE TEST, PACK 9, TEMPERATURE VERSUS TIME

CHAPTER 4

SUMMARY

The EMATT battery pack installed in the EMATT vehicle was tested under the guidelines of NAVSEA Notice 9310. The EMATT vehicle with the tested Li/SO_2 battery was recommended as safe for fleet use. The following data summarize the behavior of the unit:

- Short Circuit- A 15 amp cell pico fuse opened immediately on each unit; no venting occurred.

- High Temperature- Each battery vented in a controlled manner; the batteries remained intact; the vehicles were deformed by the heat, and no fragmentation of the vehicle occurred.

- Forced Discharge into Reversal- Cell ventings occurred immediately prior to the batteries entering voltage reversal; no deformation of the vehicle occurred; the vehicle vent operated correctly.

- Safety Device Test- The thermal fuse operated correctly on units six and nine. It is believed the thermal fuse will operate correctly; the battery will not go into reversal, and no cell venting will occur.

REFERENCES

1. "Minutes of the 32nd Meeting of the Lithium Battery Technical/Safety Group, 8-9 Oct 1986, Bloomington, IN, R. F. Bis, P. Hallal, "Update of the EMATT Program at Sippican."

2. Naval Sea Systems Command, Critical Item Product Fabrication Specification, Battery Pack Assembly (Code Indent 53711).

3 "Safety and Performance Tests for Qualification of Lithium Batteries", Enclosure (2) of "Responsibilities and Procedures for the Naval Lithium Battery Safety Program", NAVSEA Notice 9310, Naval Sea Systems Command, Washington, DC, 11 Jun 1985.

APPENDIX: PHOTOGRAPHS OF BATTERY PACK AND COMPONENTS

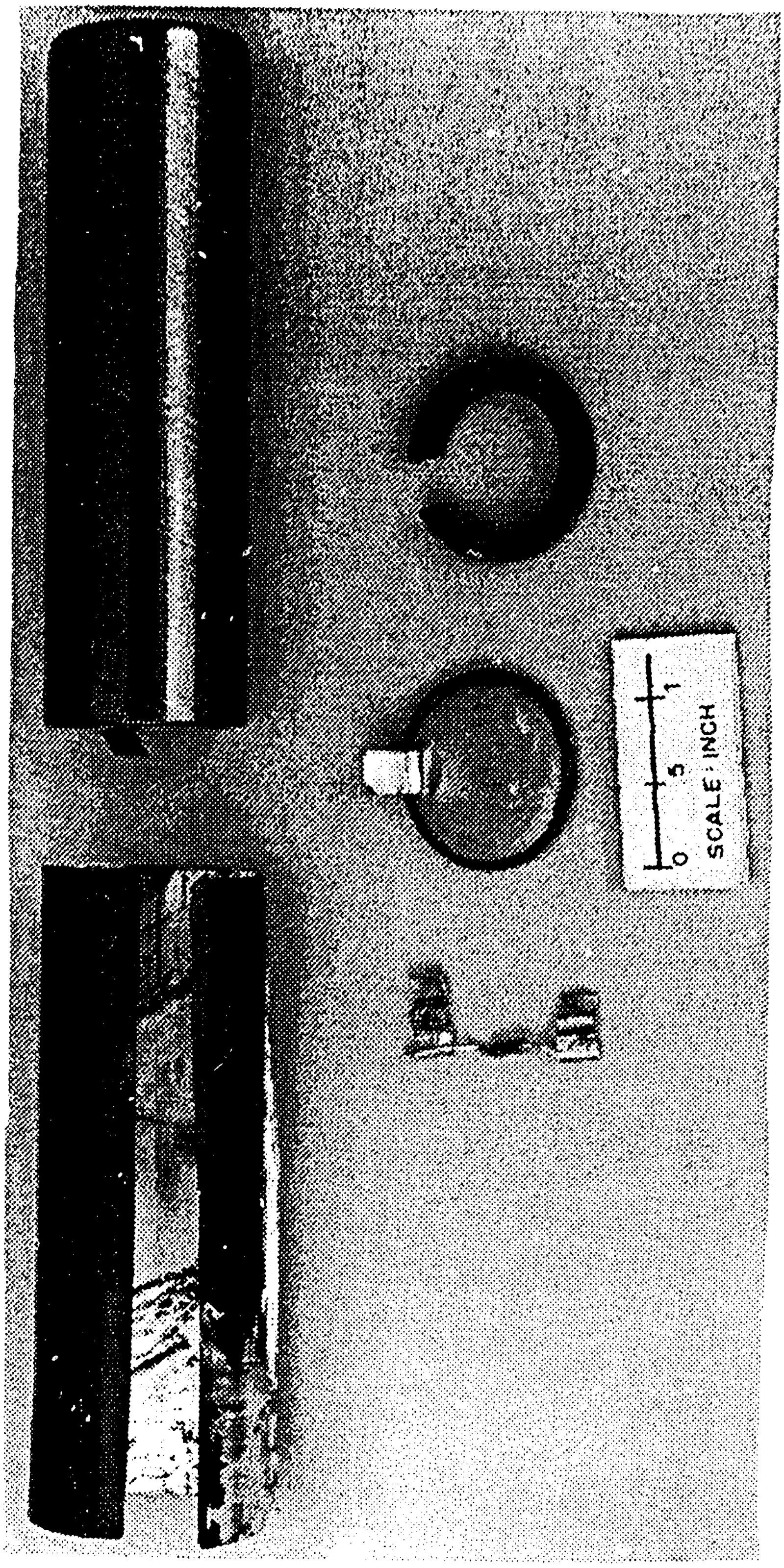

FIGURE A-1. CELL COMPONENTS: ALUMINUM CASING, CELL, 15 AMP PICO FUSE, POTTING, SPACER

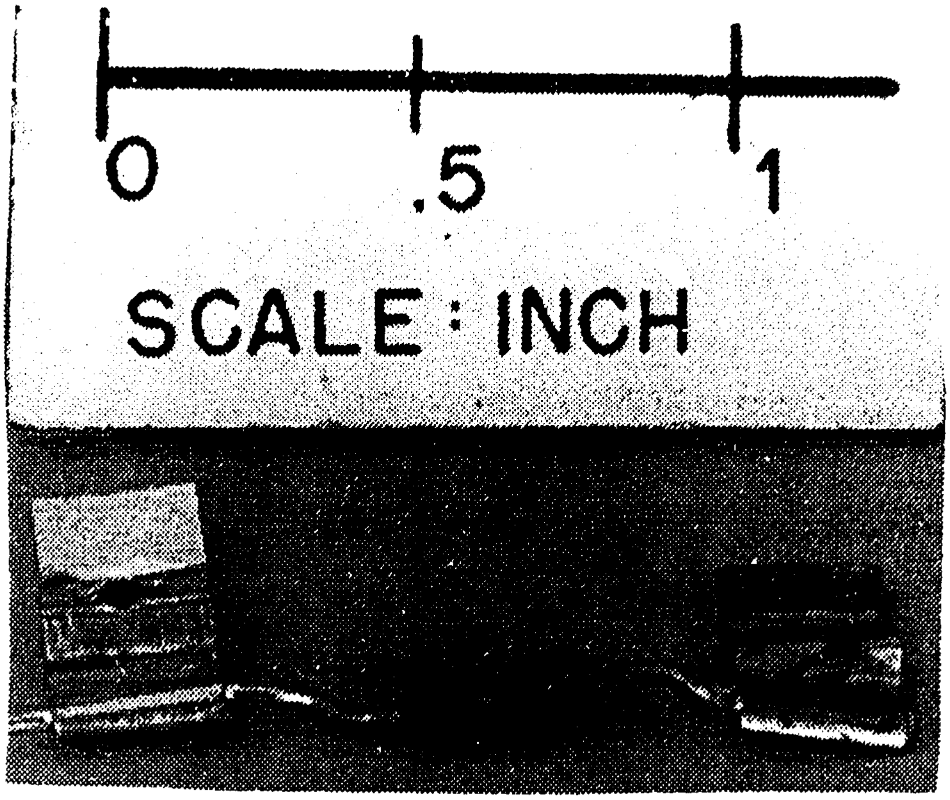

FIGURE A-2. CELL COMPONENTS: 15 AMP PICO FUSE

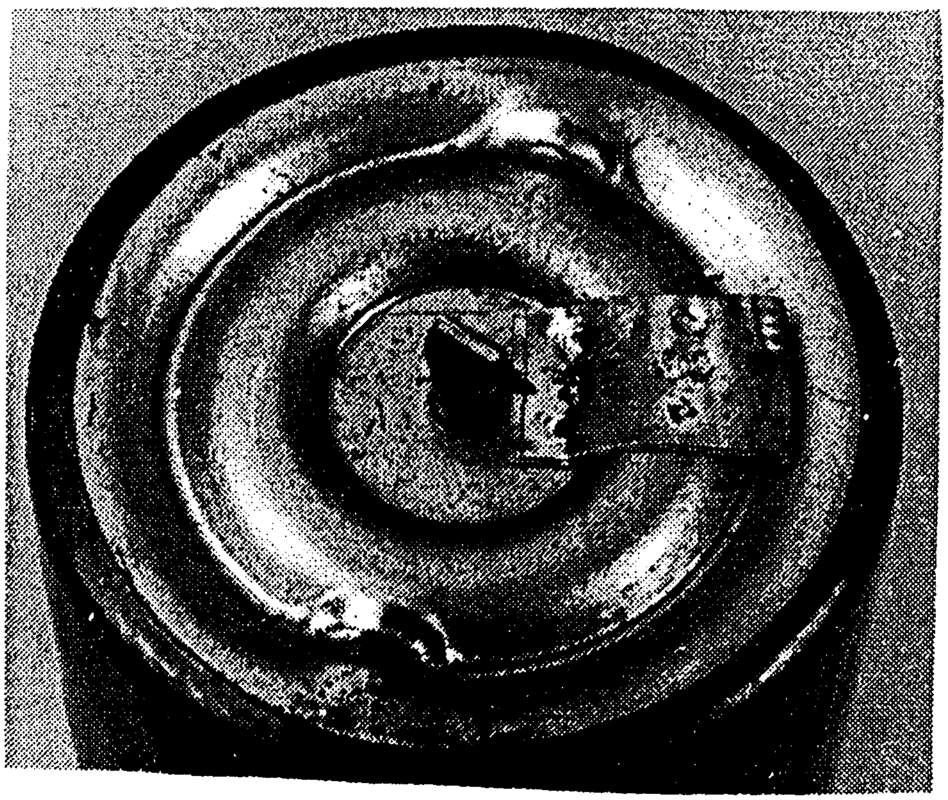

FIGURE A-3. CELL COMPONENTS: CELL, VENT END VIEW

FIGURE A-4. BATTERY PACK: SIX-CELL END VIEW

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